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# Continuous Monitoring of Seismic Energy Release Associated with the 1994 Northridge Earthquake and the 1992 Landers Earthquake

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## ABSTRACT

We have developed a method to detect long-period precursors for large earthquake observed in southern California, if they occur. The method allows us to continuously monitor seismic energy radiation over a wide frequency band to investigate slow deformation in the crust (e.g. slow earthquakes), especially before large earthquakes. We used the long-period records ($1sps$) from TERRAscope, a broadband seismic network in southern California. The method consists of dividing the record into a series of overlapping $30min$ long windows, computing the spectra over a frequency band of $0.0005 - 0.1Hz$, and plotting them in the form of a time-frequency diagram called spectrogram. This procedure is repeated daily over a day-long record. We have analyzed the January 17, 1994 Northridge earthquake ($M_w = 6.7$), and the June 28, 1992 Landers earthquake ($M_w = 7.4$). No slow precursor with spectral amplitude larger than a magnitude 3.5 was detected prior to either event. In other words, there was no precursor whose moment was larger than $\sim 0.002\%$ of the main shock.


## INTRODUCTION

The initiation of an earthquake is generally considered abrupt. However, some precursory slow slip has been reported for the 1960 Chilean earthquake (Kanamori and Cipar [1974]; Kanamori and Anderson [1975]; Cifuentes and Silver [1989]), the 1944 Tonankai earthquake (Sato [1970], [1977]; Mogi [1984]), and the 1989 Macquarie Ridge earthquake (Ihmle et al. [1993]). In particular, the leveling data before the Tonankai earthquake suggest a precursory tilt as large as 30% of that of the mainshock for a few hours prior to it. Unfortunately, data are very limited for both the Chilean earthquake and the Tonankai earthquake. Also, Kedar et al. [1994] saw no direct evidence for the precursor for the Macquarie Ridge earthquake. Hence whether or not slow precursory deformations occur under certain circumstances is not presently resolved.

In contrast, several recent studies (mainly of California earthquakes) demonstrated that if a slow precursory slip occurs , it is probably less than 1% of the mainshock in terms of seismic moment (Johnston et al. [1994],[1990] [1987]; Agnew and Wyatt, [1989]; Linde and Johnston [1989]). Also, modeling studies using velocity weakening constitutive relations predict that such precursory changes on time scales of minutes are less than 1% of the main shock moment (Lorenzetti and Tullis [1989]). Hence, whether or not slow precursory deformations occur under certain circumstances is presently unresolved.

To investigate this problem we have developed a method for continuously monitoring the long-period ($1sps$) record from TERRAscope, the Caltech/USGS southern California Broadband seismic network. We report here the results from two recent large earthquakes in Southern California: The 1994 Northridge earthquake and the 1992 Landers earthquake.

## METHOD

The long-period part of the spectrum was analyzed by means of a frequency-time diagram or "spectrogram". The spectrograms were constructed and fine tuned particularly for analysis of TERRAscope data over a frequency band $0.005 - 0.1Hz$. The computation is done by taking the frequency spectrum of a $30min$ long time window, advancing the window by ten minutes and repeating the computation. The cutoff amplitude for the spectrogram was determined for each station to emphasize signals that are slightly above noise level. This analysis is performed automatically every day on the Pasadena station (PAS).

## JANUARY 17, 1994 NORTHRIDGE EARTHQUAKE

Figure 1 shows the spectrogram for the mainshock of the 1994 Northridge earthquake and its aftershock sequence observed on the long-period component at Pasadena ($\Delta = 35km$). The window position is adjusted so that the origin time of the mainshock is at the beginning of the $30min$ long time window that includes the main shock. The aftershocks with $M \geq 3.5$ are seen, but smaller aftershocks can only be detected at periods shorter than $20s$. A long-period event whose moment is equivalent to that of a $M = 3.5$ earthquake would appear as a similar signal on the long-period (left hand) side of the spectrogram. Immediately before the mainshock, no long-period event can be detected.

A long-period signal is observed at 8:00AM at the frequency band of $0.01 - 0.05Hz$. Although the lack of short period energy associated with this signal could suggest a local slow event, a further look across the array reveals a long-period wave train coming from the northwest with a group velocity of $\sim 4km/s$ (Figure 2). We conclude that this signal is caused by a Rayleigh wave from a small teleseismic event and not by any local slow event. Figure 1 shows no slow precursory event whose long-period spectral amplitude is larger than that of $M = 3.5$ during the twelve hour period prior to the 1994 Northridge earthquake.

## JUNE 28, 1992 LANDERS EARTHQUAKE

Figure 3 displays the spectrogram for the 1992 Landers earthquake and its aftershock sequence which includes the Big Bear earthquake ($M_w = 6.5$). The records are taken from the East-West component of the Piñon Flat (PFO) station. Several events appear prior to the mainshock. A magnitude 3.6 local earthquake is observed at 5:55AM , and a teleseismic Rayleigh wave packet arrives after 6:00AM.

The spectrogram begins with a long-period (0.005-0.02$Hz$) signal which dies out by 3:00AM.

Examination of the three days prior to June 28 (Figure 4) reveals a daily pattern of background noise whose tail end decays in the beginning of June 28 and is not associated with the Landers earthquake.

An intriguing signal on the spectrogram is the one marked by a circle in Figure 3. It appears during the last time window just before the mainshock. A closeup of the last $30min$ before the mainshock (Figure 5) reveals a $\sim 6min$ long signal on the East-West component, slightly stronger than the background noise. This signal is equivalent to a tilt of $\sim 10^{-9}$ radians. However, examination of the Piñon Flat strainmeter records [Frank Wyatt, personal communication] and the Punchbowl strainmeter records [Malcolm Jhonston, personal communication] show no East-West disturbance of the same order of magnitude during this time window, which leads to the conclusion that the signal in question is a site related long-period noise.

## CONCLUSION

We have introduced a convenient method for detecting long-period irregularities on the seismic record by applying a precalibrated daily spectrogram to the long-period data channel of TERRAscope stations. We have presented two cases of interest: the 1994 Northridge earthquake and the 1992 Landers earthquake. In both cases some suspicious long-period events appeared on the spectrograms prior to the mainshock.

An examination of the twelve hour period prior to the mainshock leads us to conclude that there was no slow precursory event whose long-period spectral amplitude is larger than that of magnitude 3.5 during the twelve hour period prior to the 1994 Northridge earthquake. In other words, there was no precursor whose moment was larger than $\sim 0.002\%$ of the main shock. This result is consistent with the observation of Johnston [1994].

Similarly, no slow precursor with spectral amplitude larger than a magnitude 3.5 was detected in the twelve hours prior to the 1992 Landers earthquake. Again, this result agrees with the observation of Wyatt et al. [1994].

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## FIGURE CAPTIONS

Fig. 1. spectrogram for January 17 (1a) and 18 (1b), 1994 recorded on the long-period vertical component of the Pasadena TERRAscope station. The corresponding time series is shown in the boxes on the right hand side of the spectrograms. The mainshock and some of the observed aftershocks are marked by magnitude on the spectrogram.

Fig. 2. A 40$min$ long window around 8:00AM on January 17, 1994, at several TERRAscope stations. The questionable signal observed on the spectrogram at Pasadena has the appearance of a teleseismic Rayleigh wave propagating from the northwest.

Fig. 3. Spectrogram of the June 28, 1992 Landers earthquake and some of its aftershocks recorded on the East-West long-period component of the Piñon Flat TERRAscope station. Marked by a circle is a suspicious long-period event showing up right before the mainshock on the spectrogram.

Fig. 4. Three and a half days preceding the Landers earthquake at Piñon Flats. The horizontal component noise shows a daily cyclic pattern. The noise level from June 27 decreases into the beginning of June 28.

Fig. 5. A closeup on the last half hour prior to the mainshock of the 1992 Landers earthquake. A long-period disturbance appears on the East-West component 10 minutes prior to the main shock. The East-West component long-period acceleration is $\sim 1.5 \times 10^{-6} m/s^2$, or equivalently $\sim 1.5 \times 10^{-9}$ radians.

## REFERENCES


Agnew, D. C., and Wyatt, F. K., The 1987 Superstition Hills earthquake sequence: Strains and Tilts at Piñon Flat Observatory, *Bull. Seis. Soc. Am.*, 79, 480-492, 1989.

Cifuentes, I. L., and Silver, P. G., Low-Frequency Source Characteristics of the Great 1960 Chilean Earthquake, *J. Geophys. Res.*, 94, [B1], 643-663, 1989.

Ihmle, P. F., Harabaglia, P., and Jordan, T. H., Teleseismic detection of a slow precursor to the Great 1989 Macquarie Ridge earthquake, *Science*, 261, 177-183, 1993.

Johnston, M. J. S., Continuous borehole strain before, during, and after the January 17, 1994 M 6.7 Northridge, California, earthquake (abstract), in *The 89th Annual Meeting of the Seismological Society of America*, Seismological Society of America, Pasadena, 1994.

Johnston, M. J. S., Linde, A. T., and Agnew, D. C., Continuous borehole strain in the San Andreas fault zone before, during, and after the 28 June 1992, $M_w$ 7.3 Landers, California, earthquake, *Bull. Seis. soc. Am.*, 84, 799-805, 1994.

Johnston, M. J. S., Linde, A. T., and Galdwin, M. T., Near-field high resolution strain measurements prior to the October 18, 1989, Loma Prieta, $M_s$ 7.1, earthquake, *Geophys. Res. Lett.*, 17, 1777-1780, 1990.

Johnston, M. J. S., Linde, A. T., Galdwin, M. T., and Borcherdt, R. D., Fault failure with moderate earthquakes, *Tectonophysics*, 144, 189-206, 1987.

Kanamori, H., and Anderson, D. L., Amplitude of the Earth's free oscillations and long-period characteristics of the earthquake source, *J. Geophys. Res.*, 80, [8], 1075-1078, 1975.

Kanamori, H., and Cipar, J. J., Focal processes of the Great Chilean earthquake May 22, 1960, *Phys. Earth. Planet. Int.*, 9, 128-136, 1974.

Kedar, S., Watada, S., and Tanimoto, T., The 1989 Macquarie Ridge earthquake: Seismic moment estimation from long-period free oscillations, *J. Geophys. Res.*, 99, 17,893-17,907, 1994.

Linde, A. T. and Johnston, M. J. S., Source parameters of the October 1, 1987, Whitier Narrows earthquake from crustal deformation data, *J. Geophys. Res.*, 94, 9633-9643, 1989.

Lorenzetti, E. and Tullis, T. E., Geodetic predictions od a strike-slip fault model: Implications for intermediate and short-term earthquake prediction, *J. Geophys. Res.*, 94, 12,343-12,361, 1989.

Mogi, K., Temporal variation of crustal deformation during the days preceding a thrust-type great earthquake - The 1944 Tonankai earthquake of Magnitude 8.1, Japan, *PAGEOPH*, 122, 765-780, 1984.

Sato, H., Crustal movements associated with the 1944 Tonankai earthquake, *J. Geod. Soc. Japan*, 15, 177-180 (in Japanese), 1970.

Sato, H., Some precursors prior to recent great earthquakes along the Nankai trough, *J. Phys. Earth*, 25, Suppl., S115-S121, 1977.

Wyatt, F. K., Agnew, D. C., and Galdwin M., Continuous measurements of crustal deformation for the 1992 Landers earthquake sequence, *J.Geophys. Res.*, 84, 768-779, 1994.

Figure 'C'

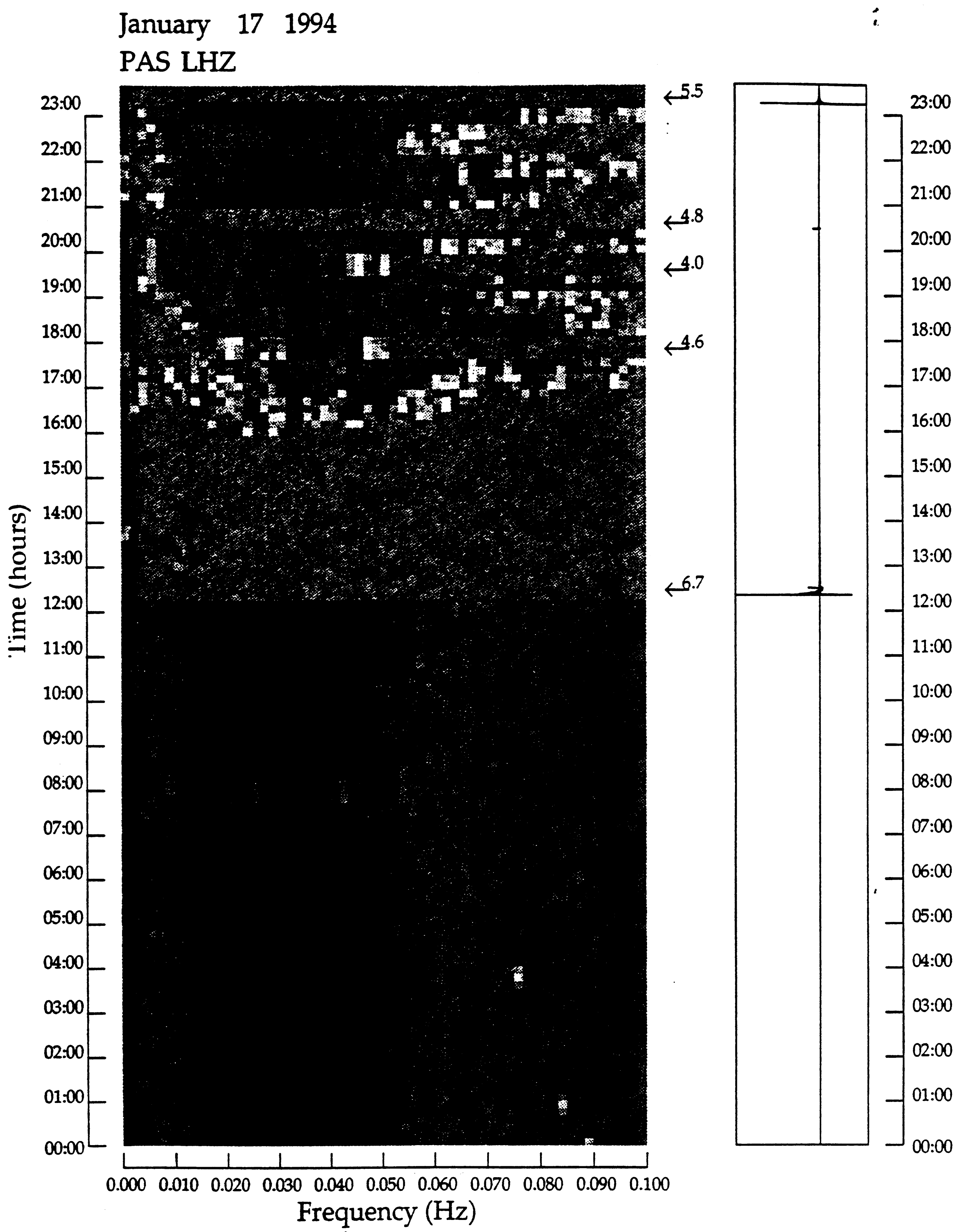

January 17 1994
PAS LHZ
Time (hours)
23:00
22:00
21:00
20:00
19:00
18:00
17:00
16:00
15:00
14:00
13:00
12:00
11:00
10:00
09:00
08:00
07:00
06:00
05:00
04:00
03:00
02:00
01:00
00:00
5.5
4.8
4.0
4.6
6.7
0.000
0.010
0.020
0.030
0.040
0.050
0.060
0.070
0.080
0.090
0.100
Frequency (Hz)

Figure 1c

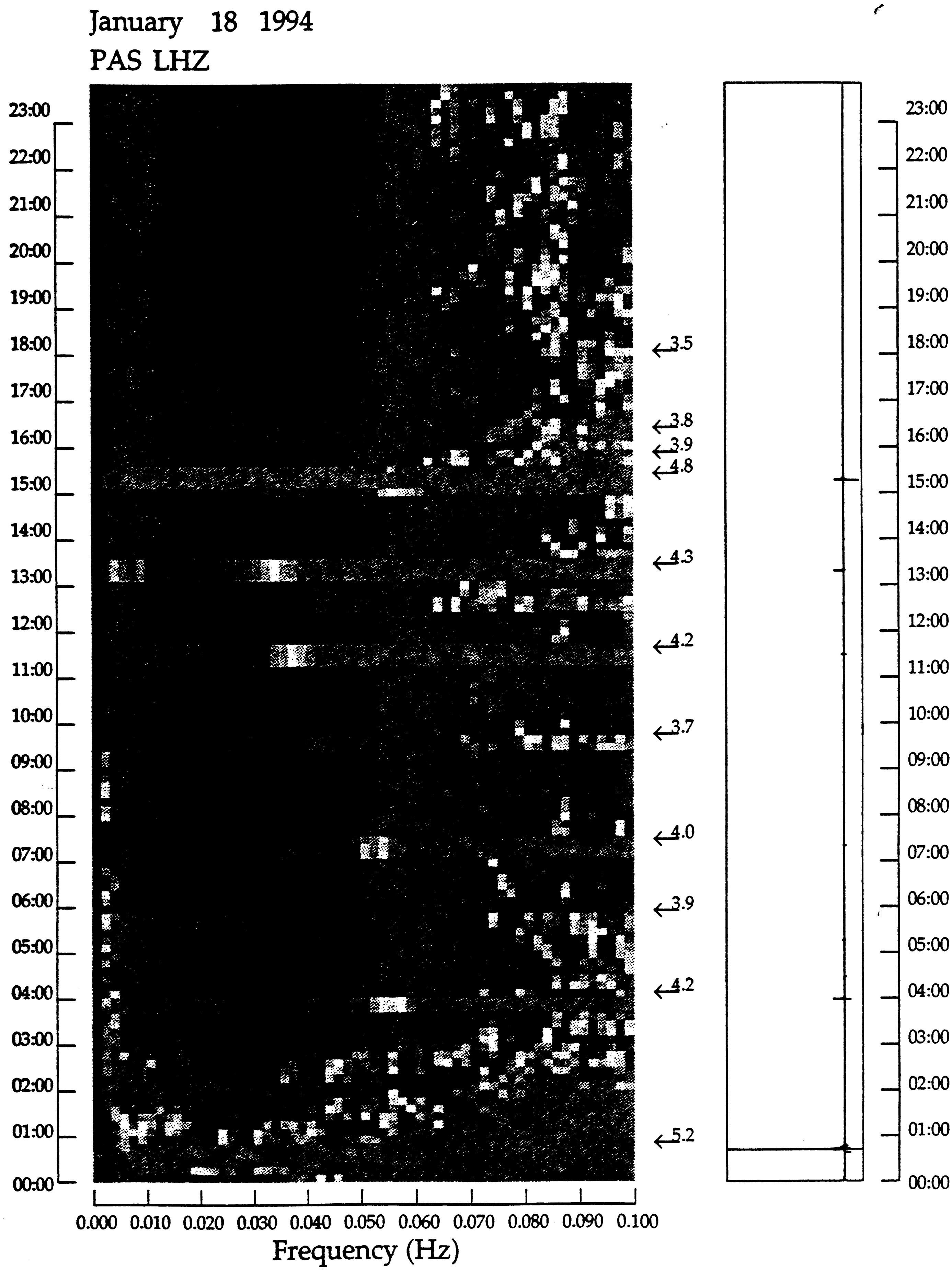

January 18 1994
PAS LHZ
23:00
22:00
21:00
20:00
19:00
18:00
17:00
16:00
15:00
14:00
13:00
12:00
11:00
10:00
09:00
08:00
07:00
06:00
05:00
04:00
03:00
02:00
01:00
00:00
3.5
3.8
3.9
4.8
4.3
4.2
3.7
4.0
3.9
4.2
5.2
0.000
0.010
0.020
0.030
0.040
0.050
0.060
0.070
0.080
0.090
0.100
Frequency (Hz)

Figure 2

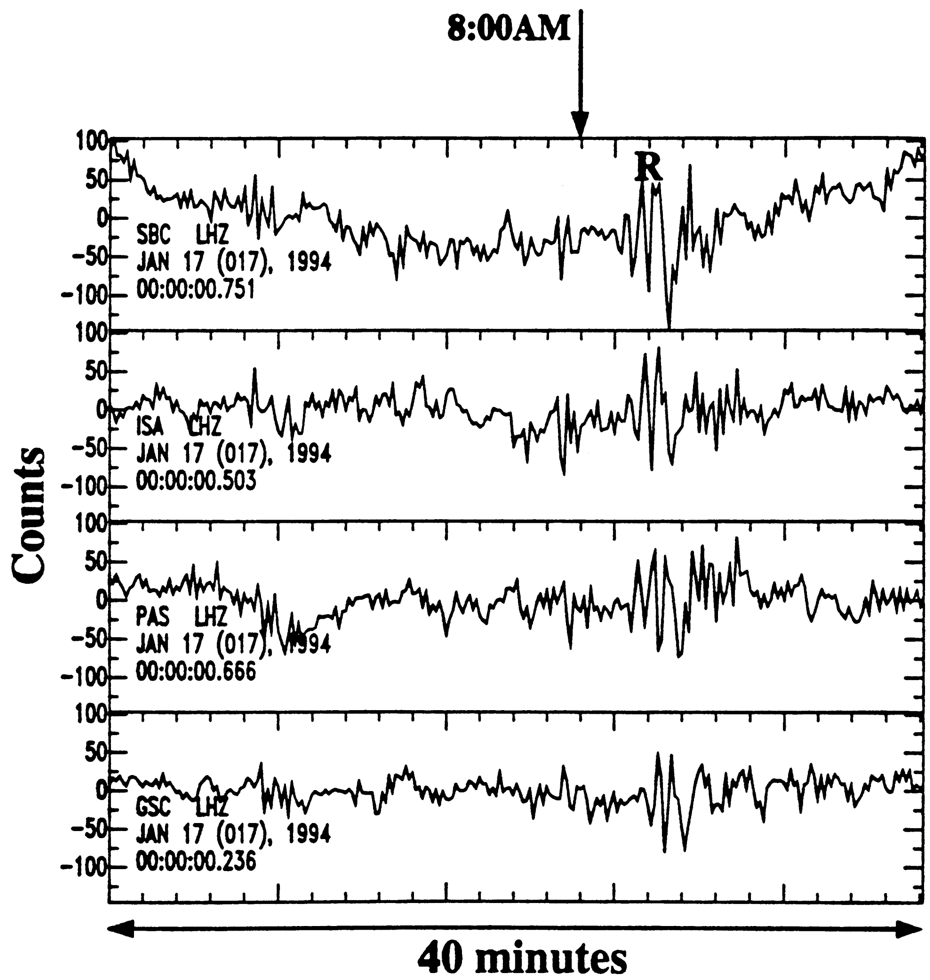
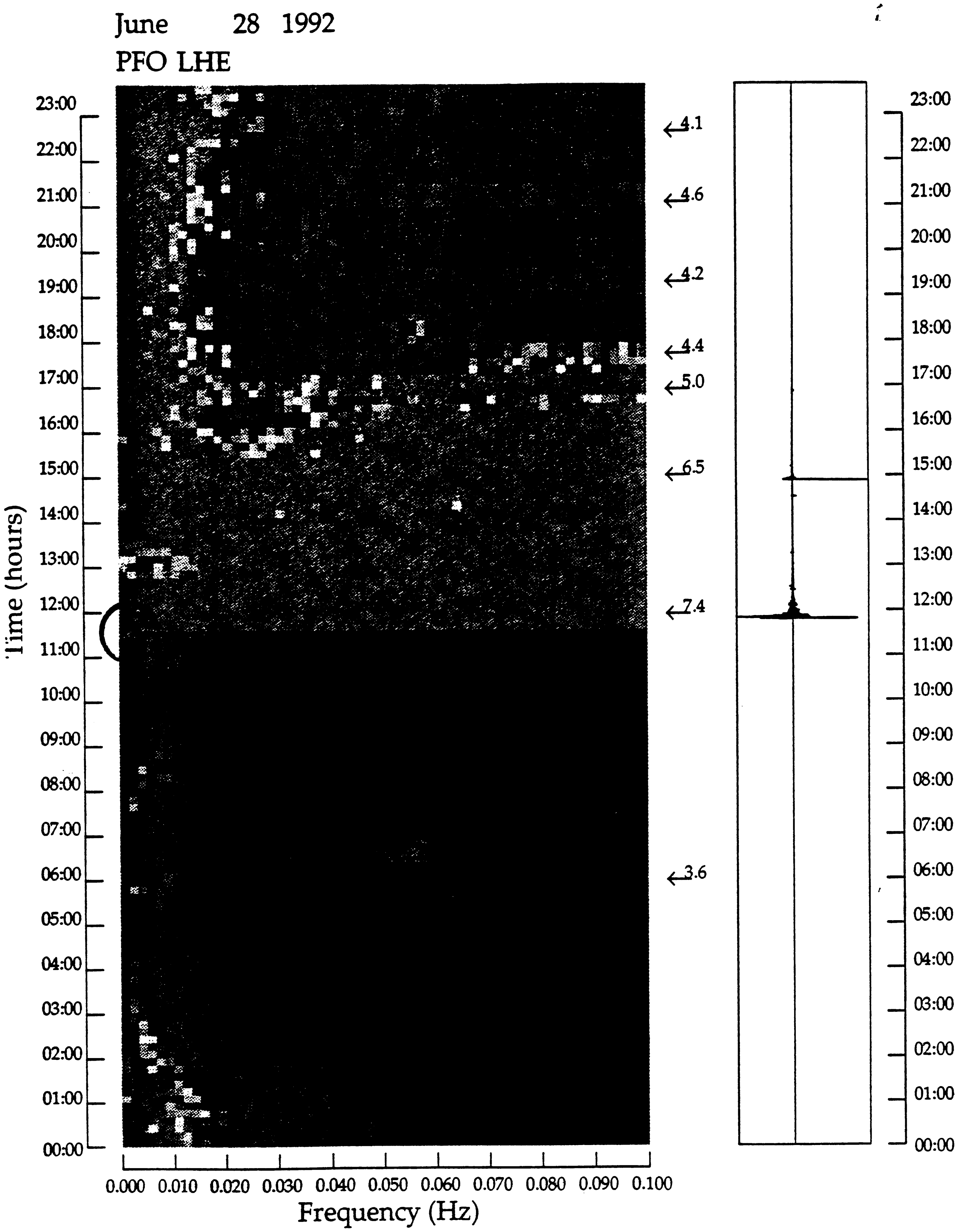

8:00AM
R
Counts
100
50
0
-50
-100
SBC LHZ
JAN 17 (017), 1994
00:00:00.751
ISA CHZ
JAN 17 (017), 1994
00:00:00.503
PAS LHZ
JAN 17 (017), 1994
00:00:00.666
GSC LHZ
JAN 17 (017), 1994
00:00:00.236
40 minutes

figure 3


June 28 1992
PFO LHE
Time (hours)
Frequency (Hz)
0.000 0.010 0.020 0.030 0.040 0.050 0.060 0.070 0.080 0.090 0.100
00:00 01:00 02:00 03:00 04:00 05:00 06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
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4.6
4.2
4.4
5.0
6.5
7.4
3.6

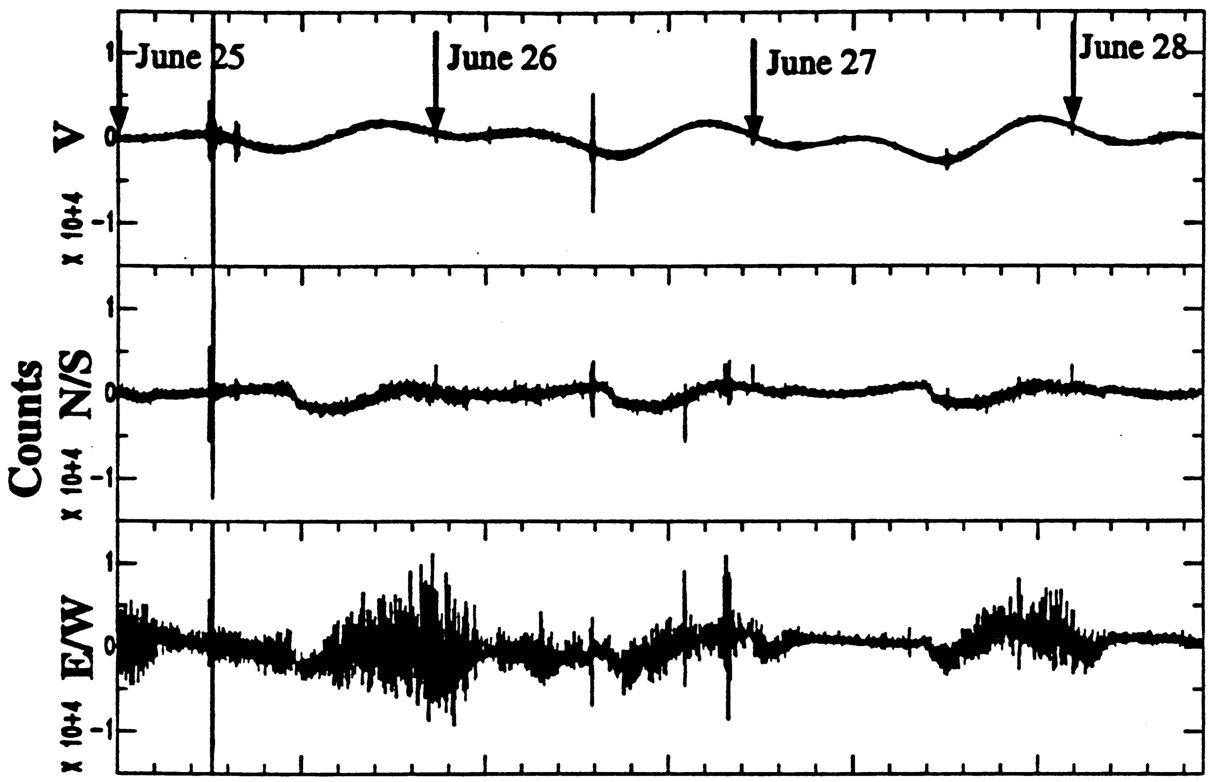
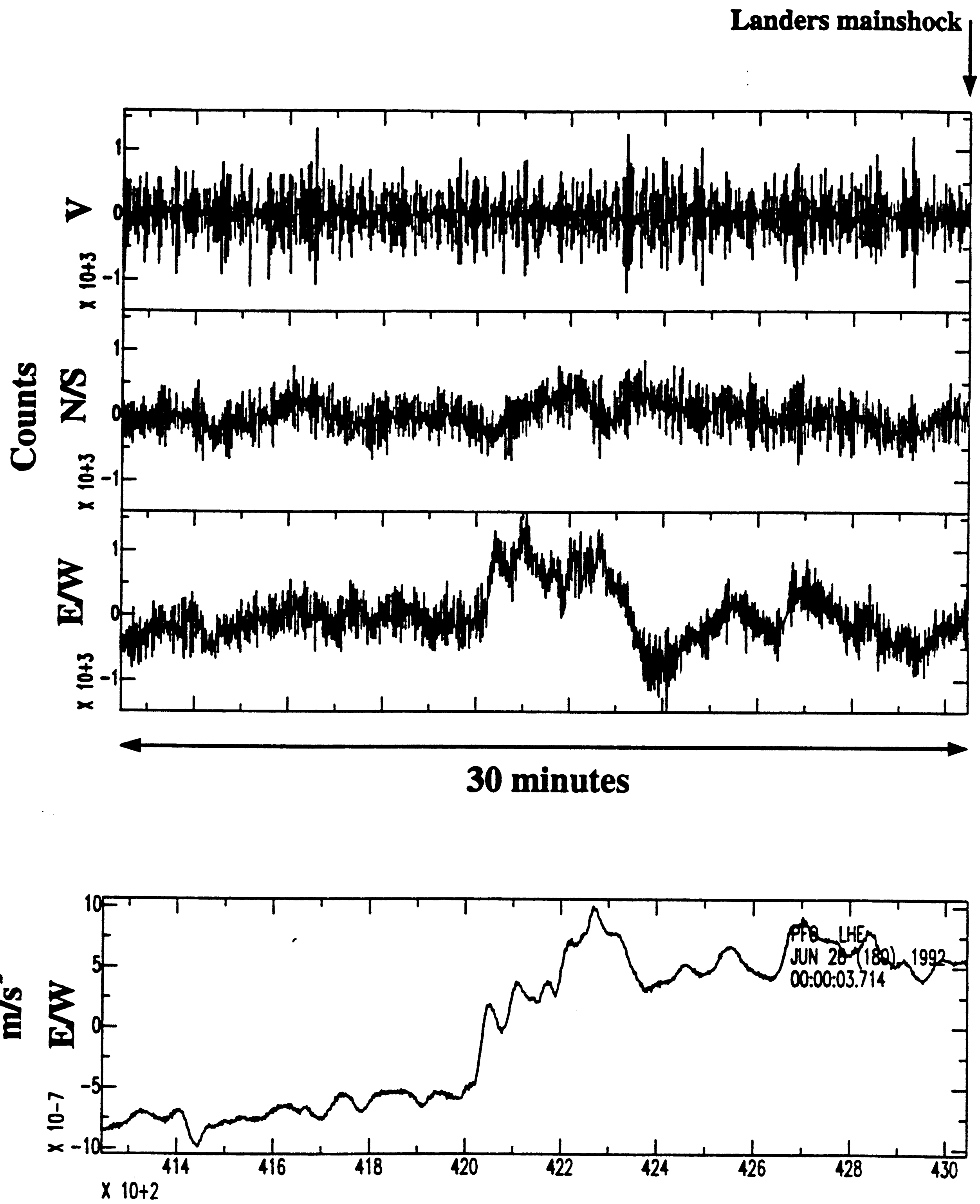

June 25
June 26
June 27
June 28
V
N/S
E/W
Counts
x 10+4
1
0
-1

Figure 5



Landers mainshock
V
N/S
E/W
Counts
x 10+3
1
0
-1
30 minutes
m/s$^2$
E/W
x 10-7
10
5
0
-5
-10
414
416
418
420
422
424
426
428
430
x 10+2
PFO LHE
JUN 28 (180), 1992
00:00:03.714